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FIRST USE OF TRITIUM AT THE NATIONAL IGNITION FACILITY

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First Use of Tritium at the National Ignition Facility*

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The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory is the world's largest and most powerful laser system for inertial confinement fusion (ICF) and experiments studying high energy density (HED) science. NIF is a 192-beam, Nd-glass laser facility that is capable of producing 1.8 MJ, 500 TW of ultraviolet light, making it over fifty times more energetic than other existing ICF facilities. The NIF Project began in 1995 and completed in 2009. Ignition experiments using tritium on NIF have just commenced. Tritium arrives at the facility in individual fuel reservoirs that are mounted and connected to a target on the Cryogenic TARget POSitioner (TARPOS). CryoTARPOS provides the cryogenic cooling systems necessary to complete the formation of the ignition target's fuel ice layer, as well as the positioning system that transports and holds the target at the center of the NIF chamber during a shot. After a shot, unburned tritium is captured by the target chamber cryopumps. Upon regeneration, the cryopump effluent is directed to the Tritium Processing System. Additional systems supporting tritium operations include area and stack tritium monitoring systems, local ventilation for contamination control, and a decontamination area that includes fume hoods and walk-in enclosures for working on contaminated components. This equipment has been used along with standard contamination control practices to manage the tritium hazard to workers and to limit releases to the environment to negligibly small amounts.

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I. INTRODUCTION

The National Ignition Facility (NIF) is a 192-beam laser facility that is capable of producing 1.8 MJ and 500 TW of ultraviolet light for performing ignition target experiments. NIF is the most recent Nd-glass laser constructed at LLNL for Inertial Confinement Fusion (ICF) and High Energy Density (HED) research. The facility is poised to produce fusion ignition in the laboratory for the first time. (Refs 1, 2, 3) At more than fifty times more energetic than previous capabilities, such as the Nova and OMEGA lasers, NIF is the world's preeminent facility for performing experiments for ICF and HED science.

The NIF laser beams are based on flashlamp-pumped 1.05-μm Nd-doped glass architecture that has been used in ICF laser facilities at LLNL for more than 30 years. At NIF, the main laser systems are installed in two laser bays. After being amplified to full energy, the beams are transported through two switchyards to the target area. At the target chamber, the beams are frequency converted to 0.35-μm light and focused onto the target in the target chamber. A layout of the facility overlaid with a model of the beam transport system is shown in Figure 1. The building is approximately 70,000 m^2 in size. Each beam has a clear aperture of about 40 × 40 cm and the facility contains about 8,000 large optics. NIF is by far the largest and most complex optical system ever built. The laser has produced over 2 MJ of 1.05-μm light and 1.3 MJ of 0.35-μm light, making NIF the only megajoule-class laser system in the world.

The NIF began as a project in 1995 and completed in 2009. Experiments at NIF using deuterium, helium-3 and helium-4 occurred during the fall of 2009, producing the first NIF neutrons. During the spring and summer of 2010, final upgrades for tritium introduction and the ignition campaign were commissioned in the facility.

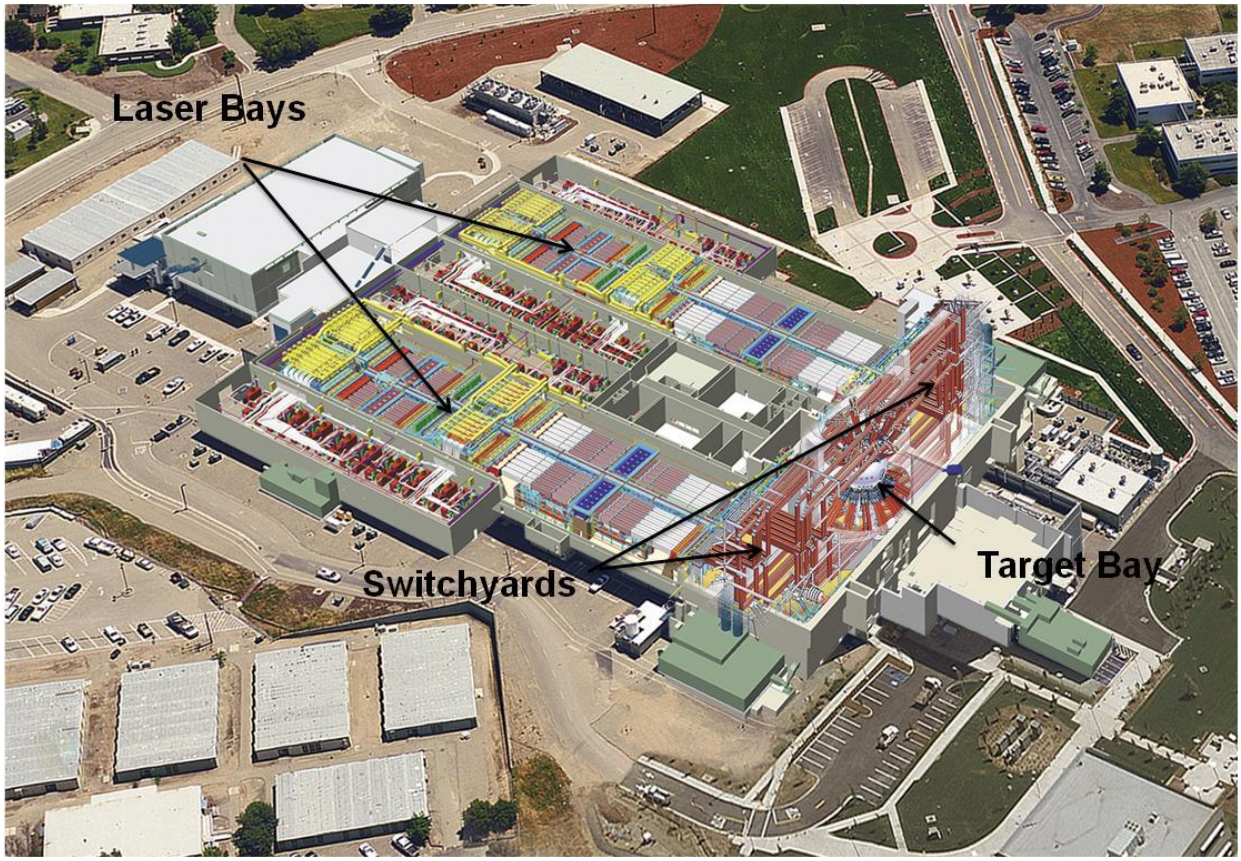

Figure 1. Layout of the NIF facility with an overlay of the laser beampath.

II. PREPARATIONS FOR TRITIUM OPERATIONS AND STARTUP PROCESS

Operational readiness requires consideration of required equipment (both engineered support systems and portable equipment), plans and procedures, and personnel training. Preparations for tritium operations at NIF began in earnest approximately two years ago. Final design, procurement, installation and commissioning of engineered systems completed in early summer of 2010. This included the Tritium Processing System, area tritium monitors, stack tritium monitors, health physics equipment, fume hoods, walk-in enclosures, and local ventilation systems. Nearly 300 operating and maintenance procedures were developed or modified to support tritium operations. In addition, over 200 workers were trained as Radiation Workers. Prior to the introduction of tritium, a prestart review activity was conducted to ensure that all equipment, procedures, and personnel were ready to commence tritium operations. The review successfully completed in late July of 2010. Tritium was introduced into the NIF in early September 2010.

III. INITIAL INTRODUCTION OF TRITIUM

Several NIF subsystems have been designed to protect workers or the environment by removing tritium from work spaces in a controlled fashion. The design of these subsystems has been based on experience in other facilities and modeling based on the known properties of tritium. Initial introduction of tritium into NIF was executed to perform the first tritium performance characterization for a number of these systems and to allow their performance to be compared to the design expectation.

The first test was performed to characterize initial behavior of tritium in the target chamber (TC) when a known quantity (3.7 GBq, 100 mCi) was injected at vacuum followed by venting with room air. This test also allowed characterization of the efficiency of the target chamber room air ventilation system for removing tritium from the target chamber, and to determine a “ventilation half-life” for tritium in the TC. The fixed tritium monitor sampling point is located at the target chamber exhaust point, but inside the vacuum volume. This allows the target

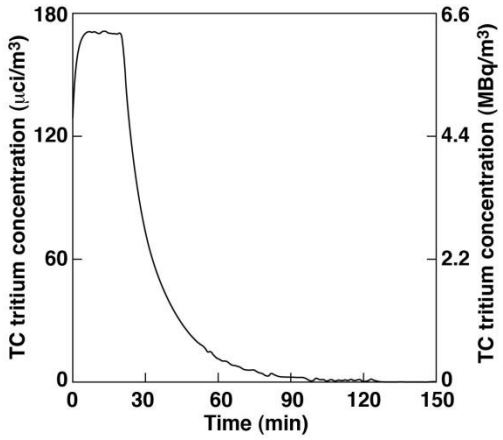

Figure 2. Plot of NIF Target Chamber tritium concentration over time, during ventilation with room air, after introduction of 3.7 GBq (100 mCi) of elemental tritium.

chamber to be sampled both under static atmosphere and ventilating conditions. A plot of TC tritium concentration with time after injection is shown in Figure 2.

We found that the measured tritium concentration from a 3.7 GBq (100-mCi) puff of elemental tritium into the target chamber (6.3 MBq/ m^3, 171 μCi/m^3) compared well to the calculated value (6.5 MBq/m^3, 176 μCi/m^3). Upon ventilating the chamber, an exponential drop in tritium concentration was observed, with a time constant of approximately 0.028 min^{-1}, or a ventilation half life of approximately 25 min. The stack monitor accounted for > 90% of the tritium introduced, indicating that < 10% had been held up on surfaces within the target chamber and ventilation ducting.

A similar injection of 3.7 GBq (100 mCi) of tritium was followed by pumping the TC to rough vacuum. Results from the stack monitor indicated essentially 100% of tritium was removed with a single vent-pump cycle. The stack monitoring system consists of Kurz mass flow system, a real-time monitor based on a femto-TECH model GC224RM-U24-D gamma compensated ion chamber and a pump/mass-flow controller combination, and an integrating monitor for official reporting. The integrating monitor is an Ortec model OS1700 tritium bubbler system that allows for precise integrated measurement of both elemental and oxide forms of tritium (HTO). These systems indicated an accumulated tritium discharge of 7.0 GBq (190 mCi) on the real-time monitor and 7.7 GBq (208.5 mCi) on the bubbler system for the estimated 7.4 GBq (200 mCi) discharge. System performance indicates that measurement of releases as low as 1.1 – 1.5 GBq (30-40 mCi) is achievable.

Another injection of 3.7 GBq (100 mCi) with a single target chamber cryopump on service was performed. The pump effluent was subsequently delivered to the Tritium Processing System (TPS) for recovery. The TPS includes two skids each capable of receiving 0.11 m^3/s (250 scfm) from the effluent of the target area vacuum systems and other incidental loads. The system is comprised of a common arrangement of heaters and catalyst beds for oxidation, and molecular sieve beds (pictured). See Figure 3. Based on the TPS skid flow rates and inlet and outlet tritium monitor values, 4.5 GBq (121 mCi) of the 3.7 GBq (100 mCi) injected was recovered. This error appears to be attributed to a spurious signal from the input monitor, leading to an integration error. TPS monitor concentration data suggest a tritium decontamination factor much greater than the system requirement of 1000.

A subsequent recovery of tritium from an unspent target reservoir containing 0.75 TBq (20.3 Ci) showed a recovery of about 0.72 TBq (19.6 Ci) with no measureable breakthrough of tritium from the TPS.

Figure 3. The NIF Tritium Processing System has achieved tritium decontamination factors greater than 1000.

IV. TRITIUM IN NIF TARGETS AND NIF SHOTS

The ignition campaign on NIF has commenced. This was preceded by an experimental program that optimized energetics, drive symmetry and ablator performance. (Ref. 4) The goal of the ignition

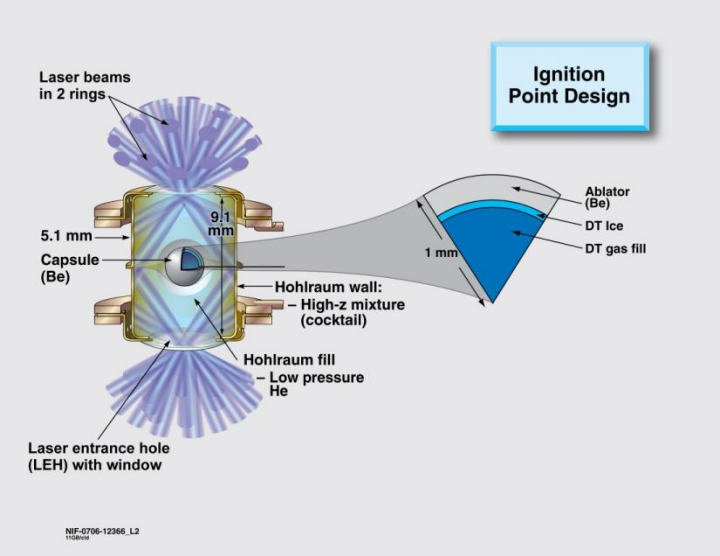

Figure 4. Schematic of the cryogenic ignition target showing the 48 "quads" of laser beams entering the hohlraum from above and below. There are four laser beams to each quad.

experiments is to produce fusion ignition and burn of a deuterium-tritium (DT) fuel mixture in millimeter-scale target capsules. The Ignition Campaign is organized around the ignition target point design. (Ref. 5) A schematic is shown in Figure 4. The indirect-drive target has a high-Z radiation case (hohlraum) with a cryogenic DT-filled capsule in the center. The hohlraum wall is a composite of depleted uranium and gold, and the hohlraum is filled with low-density He gas to control plasma filling. The point design capsule has a beryllium shell; alternate designs with high-density carbon are also being pursued. To date, we have used only gold hohlraums and plastic capsules with THD fuel (72% T; 22% H; 6% D), which effectively duds the yield by providing a tritium-rich, deuterium-poor cryogenic layer. In the near future, we will be using DT-fueled targets. Due to their associated hazards, DU (fission products) and beryllium will only be used if necessary to improve target performance.

Fuel mixes are created at LLNL's Tritium facility. Here, various ratios of H:D:T are mixed and a fuel reservoir containing approximately 0.74 TBq (20 Ci) of tritium, at 689 kPa (100 psi) is filled. Many hours before the shot, the fuel reservoir is transported to the NIF and mated to the target on the Cryogenic TARget POSitioner (CryoTARPOS).

The CryoTARPOS provides the cryogenic cooling systems necessary to complete the formation of the ignition target's fuel ice layer, and it also provides the positioning system that transports and holds the target at the center of the NIF chamber during a shot. See Figures 5 and 6. Prior to the shot, the fuel reservoir is cooled, and a valve is opened, allowing the fuel to flow into the capsule through a fine 10-μm-diameter fill tube. Once the required meniscus height is reached, the fuel reservoir is valved off, and the process to form the ice layer begins. The time line is shown in Figure 7. The cooling system ultimately cools the target to a specified temperature near 18 K. The DT will freeze and form a 75-μm thick ice layer on the interior surface of the capsule. (Ref. 6) The beta particle from tritium decay facilitates the formation of a uniform ice layer by causing localized heating and sublimation of fuel, which then re-condenses on cooler surfaces elsewhere. This "beta-layering" process, illustrated in Figure 8, creates the smooth ice layer required for ignition.

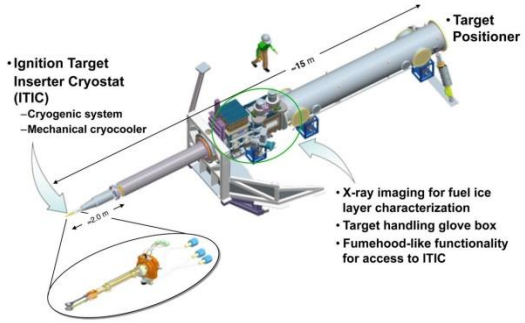

Figure 5. The Layering and characterization station is integral with the CryoTARPOS. The target assembly is mounted at the end of the boom, shown extended into the target chamber.

The CryoTARPOS provides a target characterization tool that is used to provide feedback during the ice layer formation process. The Layering and Characterization Station is mounted in the forward portion of the CryoTARPOS as shown in Figures 5 and 6.

The characterization system is based on phase contrast x-ray imaging and provides three orthogonal views of the target. This technique results in good contrast at the edges of even extremely low absorbing materials like hydrogen ice. (Ref. 7) This approach has allowed quantitative evaluation of the quality of the THD/DT ice surface in optically opaque materials like Be. Figure 9 shows an x-ray projection of solid THD in a capsule with a resolution of approximately 3 μm using this technique. Images are taken every few minutes to provide feedback for the ice formation process. This system ultimately determines when the ice has met the thickness and roughness specifications. At the conclusion of a successful fuel ice layer formation process, the imaging system is stowed, and the target is transported on the boom to target chamber center.

Having the layering and characterization capability integral with the positioning system allows the target to be moved into the target chamber through the chamber isolation valve with minimum vibration or time delays. The CryoTARPOS positions the capsule and holds it steady to within a few microns at target chamber center, all the while maintaining the temperature within milli-Kelvins of set point to preserve the carefully formed ice layer.

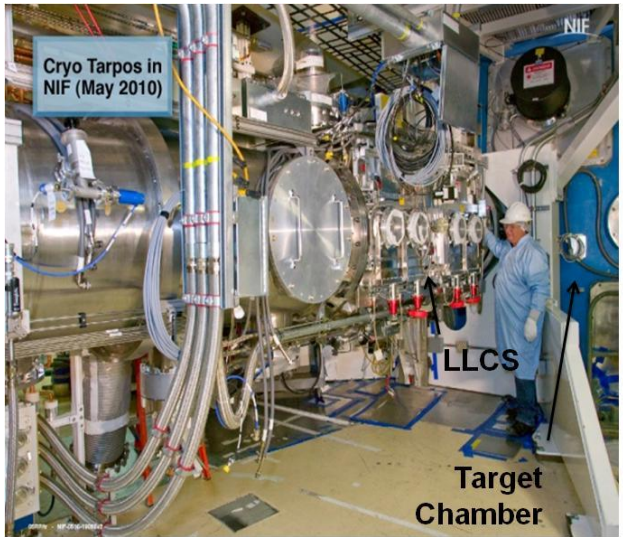

Figure 6. The CryoTARPOS is attached to the target chamber at the mid-plane. Targets are loaded at the front end of the vessel, which contains the Load Layering and Characterization Station (LLCS).

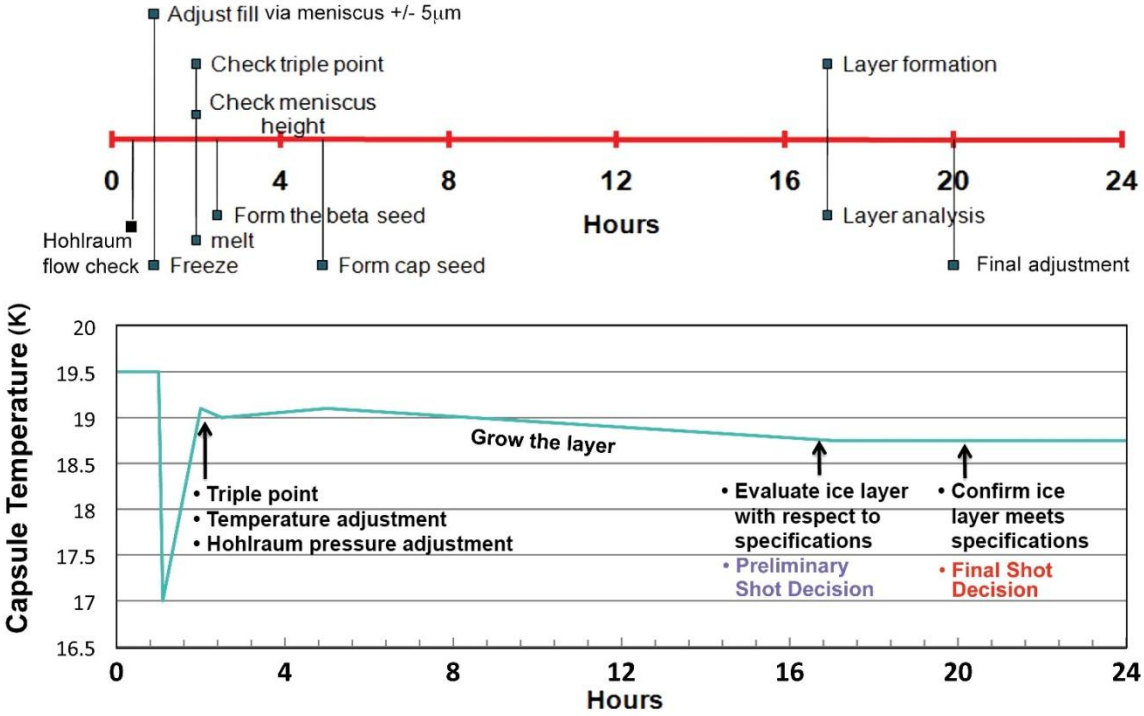

Figure 7. Layer formation time line. It takes 16 to 20 hours to form a high-quality ice layer.

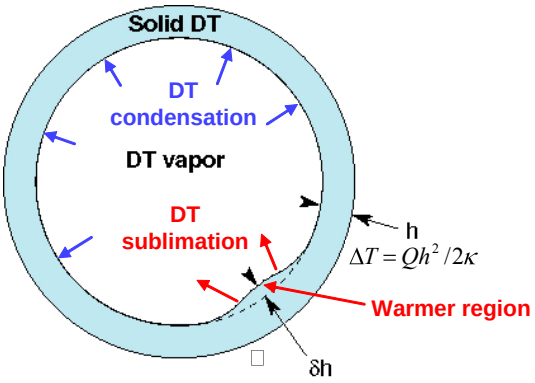

Figure 8. Beta-layering causes the bump height to decrease as DT sublimes from the warmer region (due to beta-decay of tritium) and condenses on colder surfaces (Ref. 8).

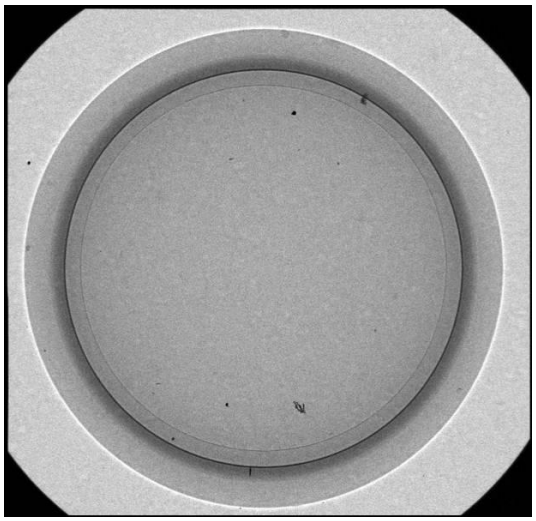

Figure 9. X-ray phase contrast image of a tritium-hydrogen-deuterium ice layer in a 2-mm diameter plastic capsule.

The total tritium throughput for operations since the beginning of September, 2010, has been approximately 3.7 TBq (100 Ci). In addition to the testing described previously, and the shots described below, tritium has been introduced in fuel reservoirs for the purpose of practicing the layering process. After layering tests, the tritium inventory was routed to TPS for recovery.

To date, NIF has executed two DT Exploding Pusher diagnostic commissioning shots. The targets for these shots were tiny glass shells, approximately 1.5 mm in diameter and containing approximately 0.93 GBq (25 mCi) of tritium. These shots produced yields in excess of 1e13 neutrons and resulted in contamination levels on items close to target chamber center (within 1 m) of 8.3 to 16.7 kBq/m^2 (5,000 to 10,000 dpm/100 cm^2).

We have also completed our first successful layered THD shot, with a neutron yield of approximately 1e13. The target for this shot consisted of a plastic capsule inside a gold hohlraum. The target contained approximately 0.37 TBq (10 Ci) of tritium, which was dispersed around the chamber during the shot. Maximum post-shot contamination levels from this shot approached 1.3 MBq/ m^2 (750,000 dpm/100 cm^2). The residual tritium in the fuel reservoir (approximately 0.37 TBq, 10 Ci) was sent directly to TPS for processing.

With these initial tritium operations, we have successfully introduced tritium into NIF and are ready to support the ignition campaign.

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